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Effects of Potato Leafhopper, *Empoasca fabae* (Harris), and Water Stress on Alfalfa Forage Yield and Quality

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ABSTRACT

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Field experiments were conducted at two locations, Becker and Rosemount, Minnesota, USA, from 1986 through 1988. The major objective is to determine the individual and interacting effects of potato leafhopper and water stress on alfalfa yield and quality. In these experiments, increases in potato leafhopper infestation consistently reduced yield. High potato leafhopper densities were required to cause decrease in plant height. On most cuttings, potato leafhopper had no effect on leaf:stem ratio. High potato leafhopper densities caused decreased herbage digestible dry matter. Moderate water stress status usually did not affect potato leafhopper distribution in the field. Water stress consistently decreased alfalfa yield. Plant height decreased when alfalfa was grown under water stress. Leaf to stem ratio was not affected by moderate water stress. Alfalfa quality was little affected by moderate water stress. Water deficit caused earlier alfalfa flowering, but potato leafhopper did not significantly affect maturity of alfalfa. Significant interactions between yield or yield value and water or potato leafhopper treatments did not occur frequently.

(Key words: alfalfa, potato leafhopper, water stress, interacting effect)

INTRODUCTION

The potato leafhopper, *Empoasca fabae* (Harris), is a major pest of alfalfa in the Midwestern and Eastern United States and is capable of injuring over 200 host plant species with preference for such crops as alfalfa, potato, bean, and cowpea[17]. Potato leafhoppers are phloem feeders. During feeding, it injects a salivary fluid which causes vascular tissue hypertrophy interfering with photosynthate translocation. Once fluid passages are blocked, plants are slow to recover, which results in stunted plants and reduced yield and quality of forage[8,12].

Although water requirements for alfalfa growth vary depending on climate, soil water supply, cultivar, and cultural practices, irrigation plays an important role in maximal production. Water stress reduces stem number, stem diameter, internode number and length, leaf size, and yield[5,22]. Moderate water stress (− 1.5 to − 2.0 MPa) reduced yield, but, concomitantly increased the proportion of leaves in the herbage[3]and was associated with increase in forage quality since alfalfa leaves contain more nutrients than stems[11]. However, with severe water stress, the leaf to stem ratio may be reduced due to leaf loss[11]. Vough & Marten[22] reported that alfalfa grown under higher water stress often had an increased percentage of *in vitro* digestibility. However, percentage of crude protein was not consistently affected. Gifford & Jensen[10] found a higher crude protein content in water stressed alfalfa. The inconsistency of the results may be due to cultivar variations in N_2 fixation capabilities[4].

Many studies have shown that potato leafhopper or plant moisture stress singly affect alfalfa yield and quality. However, information about the combined effect of these two factors is meager. Wilson et al.[23] reported that leafhopper infestations reduced plant growth 28% more on nonirrigated plots (receiving natural rainfall only) than on irrigated plots. They also pointed out that the effect of leafhopper control in the previous season on the following spring regrowth was evident in early regrowth response and increased yield. Little carry-over of irrigation effects from fall to spring was found.

Current economic thresholds are based on a single factor, potato leafhopper, which may be biased when alfalfa is subject to different water stress. The major objectives for this study is to quantify the effect of potato leafhopper and water stress on alfalfa yield and quality.

MATERIALS AND METHODS

Experiments were conducted at two locations in Minnesota, USA, the University of Minnesota Agricultural Experiment Station, Rosemount, and the University of Minnesota Sand Plain Experimental Field, Becker, over 3 growing seasons, 1986-1988. Plots were established in 1986, using cultivar "Dekalb 120" at Becker on a sandy soil, planted 21 April, and cultivar "Pioneer 520" at Rosemount on a silt-loam, planted 1 May. Plot sizes were 9.1 × 18.2 m at Becker and 18.2 × 30.5 m at Rosemount. The experiment was a split-plot design with whole plots representing water stress levels and subplots representing potato leafhopper levels. There were three replicates at Becker and four replicates at Rosemount.

Potato leafhopper treatment

Gradients of potato leafhopper infestation were obtained by weekly application of methoxychlor insecticide. Sprays of methoxychlor were applied at 1.12, 0.37, 0.11, and 0.0 kg a.i./ha at Rosemount and at 1.12, 0.37, and 0.0 kg a.i./ha at Becker, to obtain 4 lev-

els and 3 levels of potato leafhopper, respectively.

Insect populations were monitored weekly throughout the growing season by sweep-net sampling. Vacuum machine sampling was also used in 1988. One sweep-net sample of 20 pendulum sweeps was taken in each plot with a standard 38-cm-diameter sweep net. Vacuum sampling was done with a backpack suction sampler (ECHO, PB-400E, KIORITZ Corp, Japan) equipped with a 15-cm-diameter (0.018-m^2) collecting head attaching to the suction hose (6-cm-diameter). To take individual vacuum samples, the collecting head was quickly lowered into the crop until against the ground, and held there for 2 seconds. Twenty putdowns were taken from each plot. Samples were stored frozen until the leafhoppers could be counted.

Water treatment

At both locations, there were 2 rates of irrigation water. Irrigation water was applied by pivot sprinkler, to circles 30.5 m diameter at Rosemount, and circles 21.3 m diameter at Becker. Irrigation was not applied after mid-September to induce alfalfa winter-hardiness. Two methods were used to monitor soil moisture: neutron probe and the "Irrigation Scheduling Checkbook Method"[24].

At Becker, extractable soil water was monitored throughout the season using a neutron probe (Model 503, Campbell Pacific Nuclear, Pacheco, Calif.). The measurements covered the soil profile to a depth of 2.1 m. Extractable soil water was then calculated (permanent water 2.6 cm). In the high water treatment, we maintained about 17 cm of extractable water, which is approximately 85% of field capacity (20.6 cm)[3]. In the low water treatment, we maintained soil moisture of about 7 cm of extractable water which is approximately 50% of field capacity. Water was applied 5 times to nonwater stressed plots in 1986. It was applied 18 and 9 times in 1987, 25 and 13 times in 1988 to nonwater stressed and water stressed plots, respectively. Total water received (rainfall between 1 April and fourth cutting + irrigation) were 837 and 751 mm in 1986, 827 and 630 mm in 1987, 930 and 634 mm in 1988 for nonwater stressed and water stressed treatments, respectively.

At Rosemount, irrigation was scheduled by the "Irrigation Scheduling Checkbook Method" which takes into account crop root depth, available water in the root zone, allowable soil water deficit, daily crop water use, rain fall and irrigation. In this experiment, field water balance was maintained above 70% of soil capacity (allowable deficits < 30%) for the high water treatment, whereas in the low water treatment, water was not added until available water dropped below 50% of soil capacity (allowable deficits > 50%). No water gradients were created in 1986 due to frequent rainfall (totally 842 mm) throughout the season. Water was applied 12 and 7 times in 1987, 13 and 12 times in 1988 to nonwater stressed and water stressed plots, respectively. Total water received were 784 and 674 mm in 1987, 734 and 657 mm in 1988 for nonwater stressed and water stressed treatments, respectively. Information needed for water deficit calculation was obtained from the "Irrigation Scheduling Checkbook Method", except that we determined the alfalfa rooting depth was only 61 cm because of an underground gravel layer which prevented deeper penetration. Weather data used in this method were provided for the Rosemount Agricultural Experiment Station by the National Weather Service.

Yield samples

When the alfalfa reached 10% bloom, yield was estimated by harvesting a 0.91 × 6.1

m swath from each plot with a flail-type small plot harvester. Fresh weights were recorded and a subsample (ca. 1 kg) taken to determine dry weights. A 61 × 61 cm area of alfalfa was sampled from a nonwater stressed plot for maturity rating except that six samples, one for each possible combination of water and potato leafhopper treatment, were taken for the second and third cutting in 1988. Plant maturity was measured as "mean stage by count" which is the average of the individual stages present in the herbage sample, weighted for number of stems in each stage (where 3 represents early bud stage; 4, bud stage; and 5, early flower stage)[13]. Mean stage by count for second and third cuttings of 1988 at Becker were pooled and analyzed as two replicates.

Plant quality mesurement

To prepare plant samples for quality measurements, alfalfa was cut 5 cm above the soil surface at three sites in each plot. Fresh cut alfalfa samples were transferred to cloth bags (for better ventilation), and dried in a forced air oven at 60℃ for 48 hours. Dry samples were separated into leaves and stems and weighed.

Leaf to stem weight ratio was determined by dividing leaf weight by stem weight. Samples were coarsely ground with a general Wiley mill fitted with a 2 mm screen, and then fine ground through a 1 mm screen with a cyclone mill to increase particle uniformity. The mill was cleaned between samples to minimize cross-contamination. Samples were tumbled for 30 min before quality analysis. Near infrared reflectance spectroscopy was used to determine percentage of crude protein and *in vitro* digestible dry matter (IVD DM) in forage.

Yield value

Dollar value of yields were computed using a modified replacement feed-cost analysis developed by Craven & Hasbargen[6]. The dollar value of the crude protein and total digestible nutrients of alfalfa (estimated from IVDDM) was computed assuming the cost of an equivalent ration of soybean meal at $154/metric ton and corn at $67/metric ton.

RESULTS

Effects of stress

Water and potato leafhopper treatments often had significant effects on forage characteristics, yield, and quality (Table 1). Usually, there was no significant interaction between these two main effects.

Independent effects of water

Water treatments differed significantly in dry matter yields at Becker on second cutting 1986, on third cutting 1987, and on second and third cuttings 1988, and at Rosemount on second and third cuttings 1987, and on second, third and fourth cuttings 1988. Dry matter yield was consistently reduced by water stress (Table 1). Effects of water stress were most commonly observed on second and third cuttings. On first and fourth cuttings, it was often impossible to establish treatment moisture because of high available soil moisture.

Plant height was consistently reduced by water stress. Significant reductions in plant height occurred at Becker on third and fourth cuttings 1987, and second and third cuttings 1988. Significant reductions in plant height occurred at Rosemount on second cutting 1987, and second and fourth cuttings 1988. High yield was generally associated with high plant height.

Water stress results in significant increases in leaf to stem ratio only at Becker on third cutting 1988. That cutting was severely moisture stressed (less than 50%

Table 1. Significant effects of water stress and potato leafhopper on forage characteristics, yield, and yield value, Becker and Rosemount, Minn., 1986-1988. [1), 2)]

Variable	Water	PLH	Water*PLH
Yield	Becker, 1986-2nd, P=0.023 ↓	Becker, 1986-2nd, P=0.023	
		Becker, 1987-1st, P=0.001	Becker, 1987-1st, P=0.006
	Becker, 1987-2nd, P=0.049	Becker, 1987-2nd, P=0.036	Becker, 1987-2nd, P=0.032
	Becker, 1987-3rd, P=0.035 ↓		
	Becker, 1988-2nd, P=0.004 ↓	Becker, 1988-2nd, P=0.021 ↓	
	Becker, 1988-3rd, P=0.007 ↓	Becker, 1988-3rd, P=0.047 ↓	
		Becker, 1988-4th, P=0.023 ↓	
	Rosemount, 1987-2nd, P=0.000 ↓	Rosemount, 1987-2nd, P=0.001 ↓	
	Rosemount, 1987-3rd, P=0.000 ↓	Rosemount, 1987-3rd, P=0.019 ↓	
		Rosemount, 1987-4th, P=0.000 ↓	
	Rosemount, 1988-2nd, P=0.049 ↓	Rosemount, 1988-2nd, P=0.001 ↓	
	Rosemount, 1988-3rd, P=0.013 ↓		
	Rosemount, 1988-4th, P=0.002 ↓		
Plant height		Becker, 1987-1st, P=0.004	Becker, 1987-1st, P=0.011
	Becker, 1987-2nd, P=0.049	Becker, 1987-2nd, P=0.005	Becker, 1987-2nd, P=0.012
	Becker, 1987-3rd, P=0.014 ↓		
	Becker, 1987-4th, P=0.009 ↓		
	Becker, 1988-2nd, P=0.026 ↓		
	Becker, 1988-3rd, P=0.006 ↓		
		Becker, 1988-4th, P=0.048 ↓	
	Rosemount, 1987-2nd, P=0.026 ↓		
		Rosemount, 1987-3rd, P=0.009 ↓	
	Rosemount, 1988-2nd, P=0.042 ↓		
	Rosemount, 1988-4th, P=0.030 ↓		
Leaf-stem ratio	Becker, 1988-3rd, P=0.035 ↑	Becker, 1988-3rd, P=0.008	
% CP leaf	Becker, 1986-2nd, P=0.023 ↓	Becker, 1986-2nd, P=0.017 ↓	
	Becker, 1987-2nd, P=0.039 ↓	Becker, 1987-2nd, P=0.045 ↓	
		Becker, 1987-3rd, P=0.000 ↓	
		Becker, 1987-4th, P=0.002	Becker, 1987-4th, P=0.018
		Becker, 1988-3rd, P=0.001 ↓	
		Becker, 1988-4th, P=0.000 ↓	
	Rosemount, 1987-1st, P=0.001 ↓		
	Rosemount, 1987-3rd, P=0.007 ↓	Rosemount, 1987-3rd, P=0.018 ↓	
	Rosemount, 1988-1st, P=0.014 ↑		
% CP stem	Becker, 1986-2nd, P=0.021 ↑		
	Becker, 1987-2nd, P=0.021 ↓		
	Becker, 1987-3rd, P=0.030 ↓	Becker, 1987-3rd, P=0.017	
	Becker, 1988-2nd, P=0.019	Becker, 1988-2nd, P=0.017	Becker, 1988-2nd, P=0.040
	Becker, 1988-3rd, P=0.013 ↓		
	Rosemount, 1987-1st, P=0.024 ↓	Rosemount, 1987-1st, P=0.024 ↓	
(continued)			Rosemount, 1987-2nd, P=0.018

	Rosemount, 1987-3rd, P=0.017		Rosemount, 1987-3rd, P=0.001
			Rosemount, 1988-1st, P=0.019
	Rosemount, 1988-3rd, P=0.003 ↑		
% CP herbage			Becker, 1988-2nd, P=0.033
		Becker, 1987-3rd, P=0.008 ↓	
		Becker, 1988-2nd, P=0.028 ↓	
		Becker, 1988-4th, P=0.003 ↓	
	Rosemount, 1987-1st, P=0.035 ↓		
	Rosemount, 1987-3rd, P=0.001		Rosemount, 1987-3rd, P=0.007
% IVDDM leaf		Becker, 1986-2nd, P=0.049	
		Becker, 1986-3rd, P=0.007 ↓	
		Becker, 1987-1st, P=0.025 ↓	
	Becker, 1988-2nd, P=0.030 ↓		
	Rosemount, 1987-1st, P=0.046 ↓		
		Rosemount, 1987-3rd, P=0.017 ↑	
	Rosemount, 1988-1st, P=0.002 ↓		
		Rosemount, 1988-4th, P=0.017 ↑	
% IVDDM	Becker, 1986-2nd, P=0.030	Becker, 1986-2nd, P=0.037	Becker, 1986-2nd, P=0.023
stem	Becker, 1988-2nd, P=0.044		Becker, 1988-2nd, P=0.032
	Becker, 1988-3rd, P=0.016 ↓		
		Rosemount, 1987-2nd, P=0.044	
			Rosemount, 1987-3rd, P=0.037
	Rosemount, 1988-1st, P=0.043 ↑		
% IVDDM	Becker, 1988-2nd, P=0.026	Becker, 1988-2nd, P=0.001	Becker, 1988-2nd, P=0.005
herbage	Rosemount, 1987-1st, P=0.040 ↓		
			Rosemount, 1987-3rd, P=0.038
			Rosemount, 1988-4th, P=0.046
Yield value	Becker, 1986-2nd, P=0.026 ↓	Becker, 1986-2nd, P=0.028	
		Becker, 1987-1st, P=0.001	Becker, 1987-1st, P=0.008
	Becker, 1987-2nd, P=0.048 ↓		
	Becker, 1987-3rd, P=0.031 ↓		
	Becker, 1988-2nd, P=0.005	Becker, 1988-2nd, P=0.011	Becker, 1988-2nd, P=0.032
	Becker, 1988-3rd, P=0.006 ↓	Becker, 1988-3rd, P=0.036 ↓	
		Becker, 1988-4th, P=0.030 ↓	
	Rosemount, 1987-2nd, P=0.000 ↓	Rosemount, 1987-2nd, P=0.005 ↓	
	Rosemount, 1987-3rd, P=0.000 ↓	Rosemount, 1987-3rd, P=0.002 ↓	
		Rosemount, 1987-4th, P=0.010 ↓	
Yield Value		Rosemount, 1988-2nd, P=0.004 ↓	
	Rosemount, 1988-3rd, P=0.005 ↓		

1) ANOVA, SAS Institute 1985.

2) Significant increases in yield or quality corresponding to relative potato leafhopper pressure or increased water stress are indicated by the symbol ↑ , significant decreases in yield or quality corresponding to relative potato leafhopper pressure or increased water stress are indicated by the symbol ↓ .

field capacity) during early regrowth.

Water stress sometimes had significant effects on leaf crude protein and on stem crude protein. However, these effects were inconsistent, with water stress sometimes associated with increased crude protein and sometimes associated with decreased crude protein. Significant differences in leaf crude protein occurred at Becker on second cutting 1986, on second cutting 1987, and at Rosemount on first and third cuttings 1987 and on first cutting 1988. Water stress resulted in significant differences in stem crude protein at Becker on second cutting 1986, on second and third cuttings 1987, and on third cutting 1988. Water stress resulted in significant differences in stem crude protein at Rosemount on first cutting 1987, and on third cutting 1988. Water stress significantly reduced herbage crude protein only at Rosemount on first cutting 1987.

Water stress sometimes had significant effects on leaf IVDDM and stem IVDDM. Significant decreases in leaf IVDDM occurred at Becker on second cutting 1988, and at Rosemount, on first cutting 1987 and first cutting 1988. Water stress resulted in significant decrease in stem IVDDM at Becker on third cutting 1988, but significant increase in stem IVDDM at Rosemount on first cutting 1988. Significant differences in herbage IVDDM occurred only at Rosemount on first cutting 1987, but that was before water gradients were established.

Water stress resulted in reduced yield value at Becker on second cutting 1986, on second and third cuttings 1987, and on third cutting 1988. Water stress resulted in reduced yield value at Rosemount on second and third cuttings 1987, and on third cutting 1988. Differences in yield value resulted primarily from reductions in dry weight yield. Effects of water stress on forage quality were of less smaller magnitude and some effects were not comsistent across cuttings.

Independent effects of potato leafhopper

Potato leafhopper pressure was usually greatest on second and third cuttings, but was most severe on fourth cutting in 1988. First cutting of alfalfa always occurred before potato leafhopper nymphs were present. Increased potato leafhopper infestation consistently resulted in yield reductions. Significant yield differences among potato leafhopper treatments were found at Becker on second cutting 1986, on second, third and fourth cuttings 1988 and at Rosemount on second, third and fourth cuttings 1987 and on second cutting 1988. Potato leafhopper infestation was associated with significant reductions of plant height only at Becker on fourth cutting 1988 and at Rosemount on third cutting 1987.

Potato leafhopper infestation resulted in increased leaf to stem ratio only at Becker on third cutting 1988. On this cutting, both intermediate and high levels of potato leafopper infestation resulted in higher leaf to stem ratios than did low level infestation. On all other cuttings, potato leafhopper treatments did not significantly affect leaf to stem ratios.

Potato leafhopper infestation consistently resulted in decreased leaf crude protein. Significant reductions in leaf curde protein occurred at Becker on second cutting 1986, on second and third cuttings 1987, on third and fourth cuttings 1988, and at Rosemount on third cutting 1987. However, treatment differences in potato leafhopper numbers were nonsignificant at Becker on second cutting 1987. Significant differences in stem crude protein occurred at Becker on third cutting 1987, but it was the intermediate potato leafhopper treatment had the lowest crude

protein. Herbage crude protein was significantly reduced at Becker on third cutting 1987, and on second and fourth cuttings 1988 (Table 1).

Potato leafhopper infestation had inconsistent effect on IVDDM. Leaf IVDDM was decreased in the high potato leafhopper treatment at Becker on third cutting 1986 and first cutting 1987, but was increased at Rosemount on third cutting 1987 and fourth cutting 1988. However, treatment differences in potato leafhopper numbers were nonsignificant at Becker on third cutting 1986. Stem IVDDM was significantly higher in the two intermediate levels of potato leafhopper infestation at Rosemount on second cutting 1987. On all other cuttings, potato leafhopper treatments did not have significant effect on stem IVDDM. Potato leafhopper treatment did not have any significant effect on herbage IVDDM.

Potato leafhopper treatments resulted in significantly different yield values at Becker on second cutting 1986, on third and fourth cuttings 1988, and at Rosemount on second, third and fourth cuttings 1987, on second cutting 1988. These differences in yield value resulted, as with water stress, primarily from effects on yield and were influenced little by effects on forage quality.

Interacting effects of water stress and potato leafhopper infestation

There were 12 instances at Becker and 7 instances at Rosemount (Table 1) in which there was a significant interaction of water and potato leafhopper with the yield or quality parameters measured. These effects seldom showed an orderly response[16] to stress gradient and the behavioral tendency was unpredictable (Fig. 1a, 1b, 2).

Significant interaction effects on yield and plant height were found at Becker on first and second cuttings 1987, on leaf crude protein at Becker on fourth cutting 1987, on stem crude protein at Becker on second cutting 1988, and at Rosemount on second and third cuttings 1987, on first cutting 1988, on herbage crude protein at Becker on second cutting 1988, and at Rosemount on third cutting 1987, on stem IVDDM at Becker on second cutting 1986, on second cutting 1988, and at Rosemount on third cutting 1987, on herbage IVDDM at Becker on second cutting 1988, on yield value at Becker on first cutting 1987 and second cutting 1988. Only three of the 19 cuttings (Becker, first and second cuttings of 1987, second cutting of 1988) in this experiment showing significant interactions in yield or yield value between water and potato leafhopper treatments suggests that this effect does not occur frequently. Significantly lower yields were found in the combined water stress and high potato leafhopper infestation compared to other treatments.

Effects of water stress and potato leafhopper on alfalfa persistence

The plots of this research received the same treatment all three crop seasons. Stem number per unit area showed that significant differences between potato leafhopper treatments ($F=5.32$, $df=2$, $P<0.05$). There was a tendency for increased stem numbers in water stressed alfalfa as potato leafhopper population increase. There was no significant difference in stem number ($F=10.77$, $df=1$, $P>0.05$) between water stressed and nonwater stressed alfalfa. Significant interaction was found between water and potato leafhopper treatments ($F=5.43$, $df=2$, $P<0.05$). Significant yield differences ($F=15.76$, $df=2$, $P<0.01$) were found among potato leafhopper treatment. There was no significant difference ($F=8.68$, $df=1$, $P>0.05$) in yield between water treatments. No interaction

($F=0.27$, $df=2$, $P>0.05$) was found between water and potato leafhopper treatments on yield.

Total alfalfa yield values of three years (1986-1988) for each combination of potato leafhopper and water stress treatments at Becker and Rosemount were compared (Fig. 3, 4). In general, at both locations total 3 years yield values decreased as the potato leafhopper population increase for both water stressed and nonwater stressed treatments. The difference of yield values between water treatments for each potato leafhopper level were generally bigger at Becker than at Rosemount. The yield value may results in part from the differences of soil types which is related to the holding capacity of water and soil fertility.

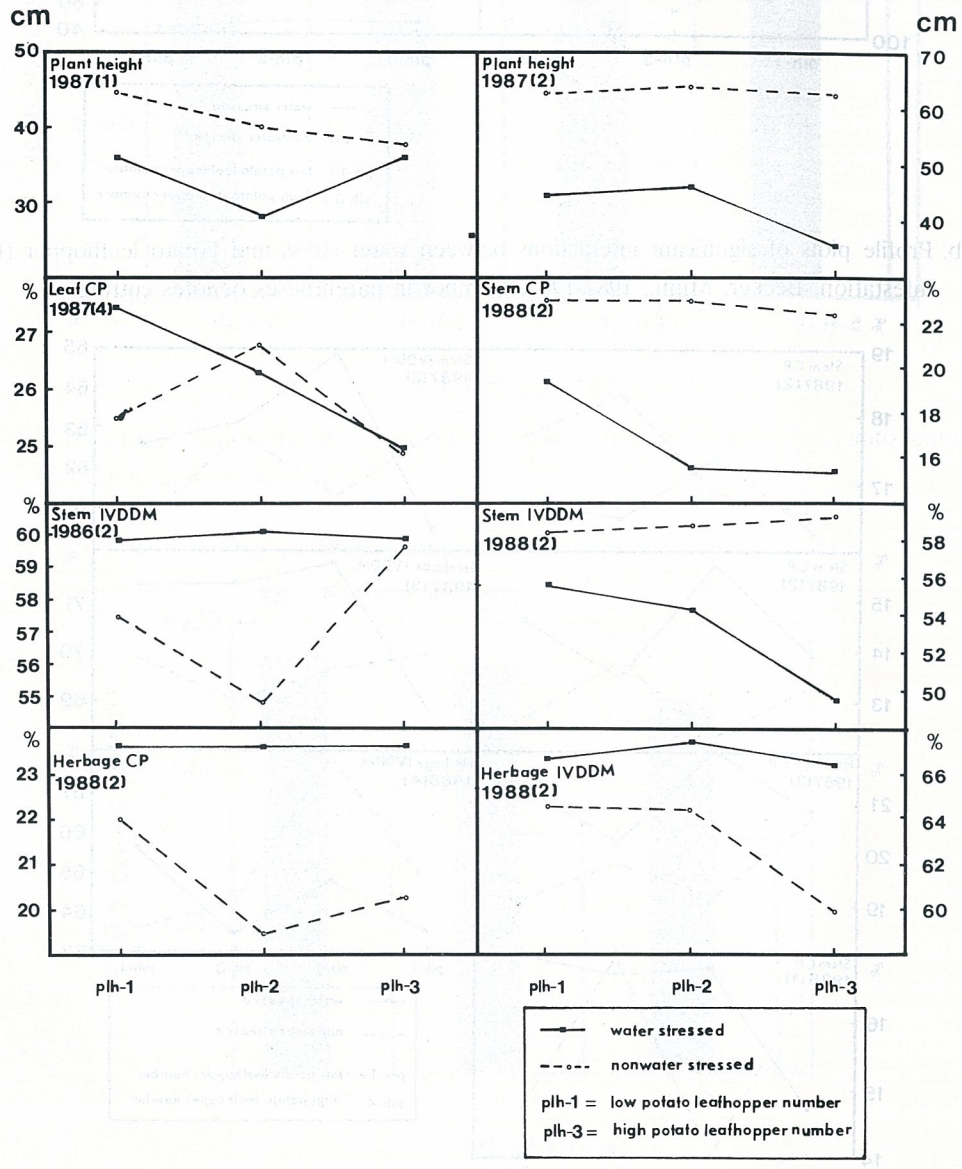

Fig 1a. Profile plots of significant interactions between water stress and potato leafhopper (PLH) infestation, Becker, Minn., 1987-1988. Number in parentheses denotes cutting.

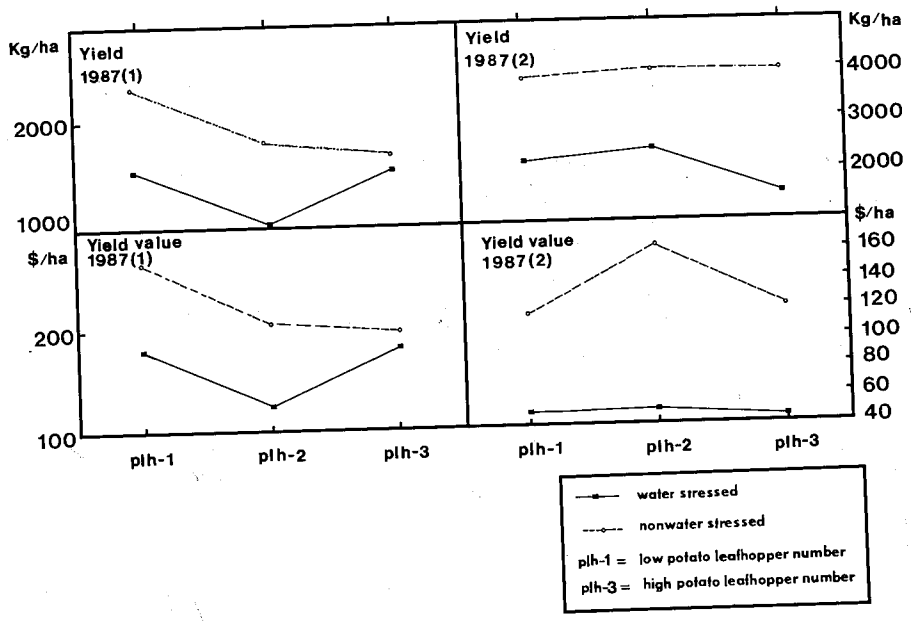

Fig 1b. Profile plots of significant interactions between water stress and potato leafhopper (PLH) infestation, Becker, Minn., 1987-1988. Number in parentheses denotes cutting.

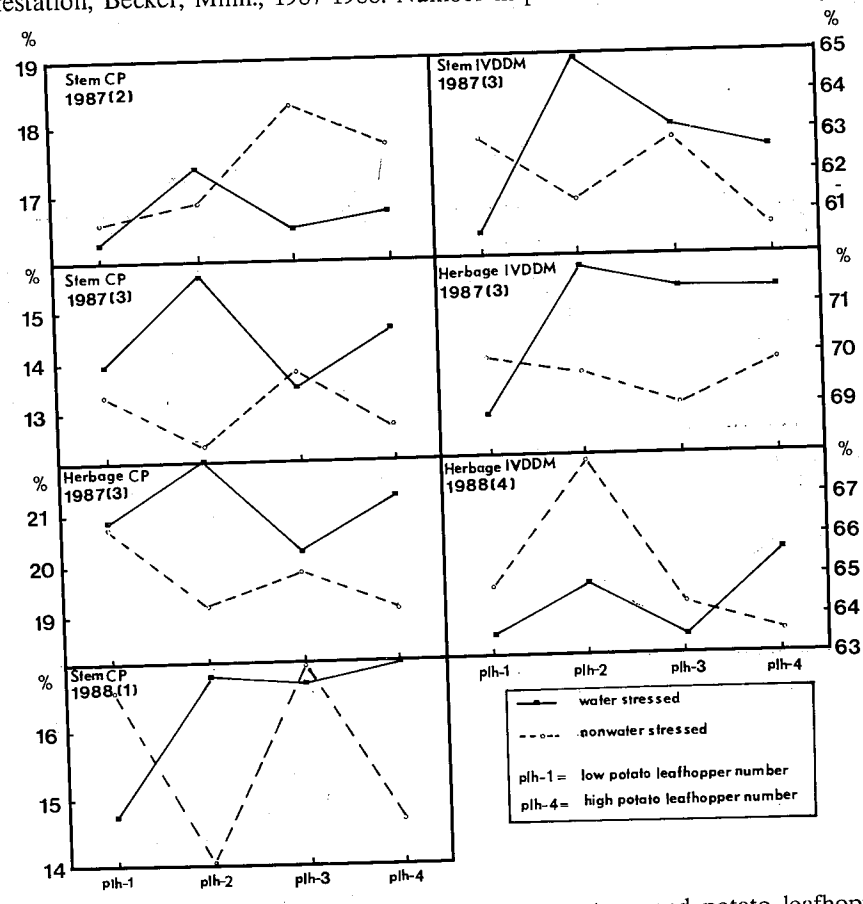

Fig 2. Profile plots of significant interactions between water stress and potato leafhopper (PLH) infestation, Rosemount, Minn., 1987-1988. Number in parentheses denotes cutting.

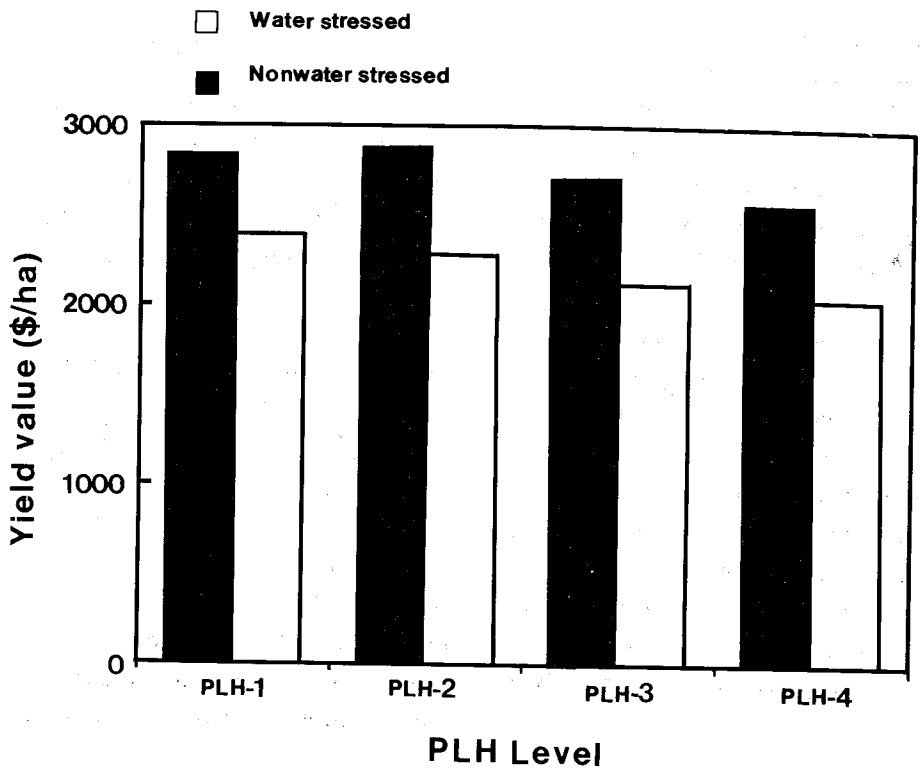

Fig 3. Total alfalfa yield values of 3 years (1986-1988) in relation to levels of potato leafhopper and water stress at Rosemount.

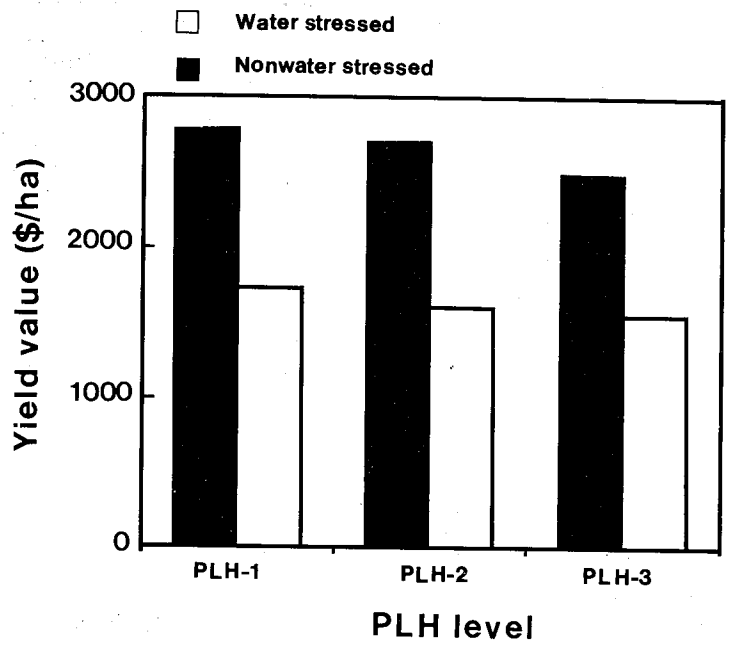

Fig 4. Total alfalfa yield values of 3 years (1986-1988) in relation to levels of potato leafhopper and water stress at Becker.

Effects of water stress and potato leafhopper infestation on maturity of alfalfa

Maturity of alfalfa stems at harvest as measured by mean stage by count ranged from 3.27-4.12 (Table 2). The results of analysis of variance showed that significant differences ($F=42.49$, $df=1, 6$; $P<0.01$) in mean stage of stems was found between two water treatments, indicating that water deficit caused earlier alfalfa flowering. Potato leafhopper did not significantly affect mean stage by count of alfalfa ($F=2.77$, $df=2, 6$; $P>0.05$). Significant interaction ($F=6.23$, $df=2, 6$; $P<0.05$). Between water stress and potato leafhopper treatments was found at Becker in 1988. In the nonwater stressed treatment, there was a tendency to earlier plant maturity with increased potato leafhopper infestation.

Discussion

Stunting of alfalfa internodes is often associated with potato leafhopper infestation [9,14,21], but in our experiment most often significant yield losses occurred without significant stem stunting. Stunting appears to result only when potato leafhopper pressure is severe. Carry-over effect of earlier leafhopper damage may be a potential problem of persistence for alfalfa through the reduction of plant vigor, since leafhopper injury affected regrowth after removal of the attacked foliage[9]. Our results showed that carry-over effect on yield from one year to another occurred at Becker in 1987 and 1989. In this research, the effect of water stress and potato leafhopper treatment on second, third and fourth regrowths of alfalfa might confound

Table 2. Maturity of alfalfa stems at harvest as measured by mean stage by count (MSC) at Becker and Rosemount, Minn., 1986-1989.

Year	Harvest	MSC[1]	
		Becker[2]	Rosemount[3]
1986	2nd cutting	3.80	3.81
	3rd cutting	4.00	3.81
1987	1st cutting	3.16	3.43
	2nd cutting	3.89	3.86
	3rd cutting	3.88	3.80
	4th cutting	3.15	3.27
1988	1st cutting	3.54	3.58
	2nd cutting	3.86	4.12
	3rd cutting	3.88	4.01
	4th cutting	3.49	3.36
1989	1st cutting	3.61	—

1) MSC = average maturity of the stages of individual stems (Kalu & Fick 1981) present in the herbage sample which was taken from a 61×61 cm area.
2) One sample was taken from a plot without water stress and high leafhopper potato numbers.
3) One sample was taken from a plot without water stress and intermediate potato leafhopper numbers.

with the carry-over effect from one cut to the next, if they did occur.

No yield difference caused by water treatment of the previous year was found at both locations throughout the entire research. This indicated that alfalfa recover well even they had been water stressed for three and two consecutive years at Becker and Rosemount, respectively. Through the results we found, in most cases yield loss occurred before the yellowing symptom appeared. This revealed a potential problem of potato leafhopper management which often being overlooked when grower justify pest control depending on plant appearance.

According to Cowett & Sprague[5], the number of stems was greater where alfalfa were grown under high soil moisture during the early regrowth, regardless of the crown size at the previous harvest. Brown & Tanner [1] also found that when water deficits existed in alfalfa during the first 14 days of regrowth, there was a significant stem density decrease. Our results showed that stem density of alfalfa was not affected by moderate water stress. Faris et al.[9] pointed out that alfalfa plants weakened by potato leafhopper attack may have less stand persistence. However, alfalfa has a remarkable ability to adjust the number of stems, depending on competition among existing plants[2].

Increase in the mumber of stems per unit area is often accompanied by increased yields[5], however, this did not occur in our experiment (Table 3).

Lamp et al.[15] found that in the second year of a two year study potato leafhopper damaged alfalfa matured earlier than did insecticide protected alfalfa. In our experiment, the inconsistence of the effect of potato leafhopper on alfalfa maturity might be due to the abundance of potato leafhopper and the involvement of other factors which also affect alfalfa maturity.

Most investigations show that cutting alfalfa at 10% flowering is the best compromise in terms of acceptable yield, forage quality and stand persistence[20]. If this practice was followed for alfalfa under water stress, the regrowth period between cuttings would be closer than for nonwater stress alfalfa. This would suppress potato leafhopper numbers since fewer nymphs would be able to complete development. However, drought usually is accompanied with hot weather which may accelerate leafhopper's development. Reach-

Table 3. Yield and stem density of the fourth year alfalfa under different regimes of water stress[1] and PLH infestation[2), 3)]. First cutting, Becker, Minn., 1989

	Water stressed			Nonwater stressed		
	PLH-1	PLH-2	PLH-3	PLH-1	PLH-2	PLH-3
Stem density (no./0.093m^2)	39.5a	48.7ab	58.1b	39.4a	40.9a	39.4a
Dry matter yield (kg/ha)	2300bc	1966bcd	1602d	2767a	2394ab	1874cd

1) Soil water was maintained at 50% and 85% of field capacity for water stressed and nonwater stressed treatments, respectively.

2) PLH-1, PLH-2, and PLH-3 represent gradients of potato leafhopper infestation created by application of methoxychlor insecticide at 1.12, 0.37, and 0.0 kg AI/ha, respectively.

3) Means followed by the same letter within the same row are not significantly different at P=0.05 by Duncan's Multiple Range Test.

ing the adult stage is critical for leafhopper to disperse and survive. Simonet & Pienkowski[19] reported that 95% of the nymphal population was reduced when alfalfa was cut to 2- to 5-cm height and similar results were also reported by Cuperus et al.[7] and Radcliffe et al.[18] Thus, potato leafhopper management may be closely related to water management in alfalfa production and may need to be refined as according to cultural practices.

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摘　要

陳健忠[1] E. B. Radcliffe[2] C. C. Sheaffer[3] G. C. Marten[3] 1990. 馬鈴薯姬葉蟬和水對苜蓿產量及品質之影響 植保會刊 32:203~217.（1. 台中縣霧峰鄉台灣省農業試驗所，2. 美國明尼蘇達大學昆蟲系，3. 美國明尼蘇達大學農藝及植物遺傳系。）

馬鈴薯姬葉蟬（*Empoasca fabae*）爲美國苜蓿和馬鈴薯之主要害蟲。本試驗自 1986 至 1988 年，分別於美國明尼蘇達州的 Becker 和 Rosemount 兩地進行。主要的目的在探討馬鈴薯姬葉蟬和水對苜蓿產量及品質的效應及此兩因子之交感作用。結果顯示增加馬鈴薯姬葉蟬爲害導致苜蓿減產，較高的葉蟬族群密度方足以降低株高。大部份的結果顯示葉對莖的重量比並不受此害蟲的影響。高馬鈴薯姬葉蟬密度減少植株可消化性乾物質之百分率，苜蓿中度缺水並不會影響葉蟬的田間族群分布。缺水導致苜蓿減產，株高也降低但是葉對莖重量比不受影響。苜宿的品質在中度缺水情況下仍不受影響。馬鈴薯姬葉蟬和水對產量和品質之交感作用並不經常發生。苜蓿缺水會造成提早開花但是馬鈴薯姬葉蟬並不影響苜蓿之成熟期。

（關鍵字：苜蓿、馬鈴薯姬葉蟬、水因子、交感作用）